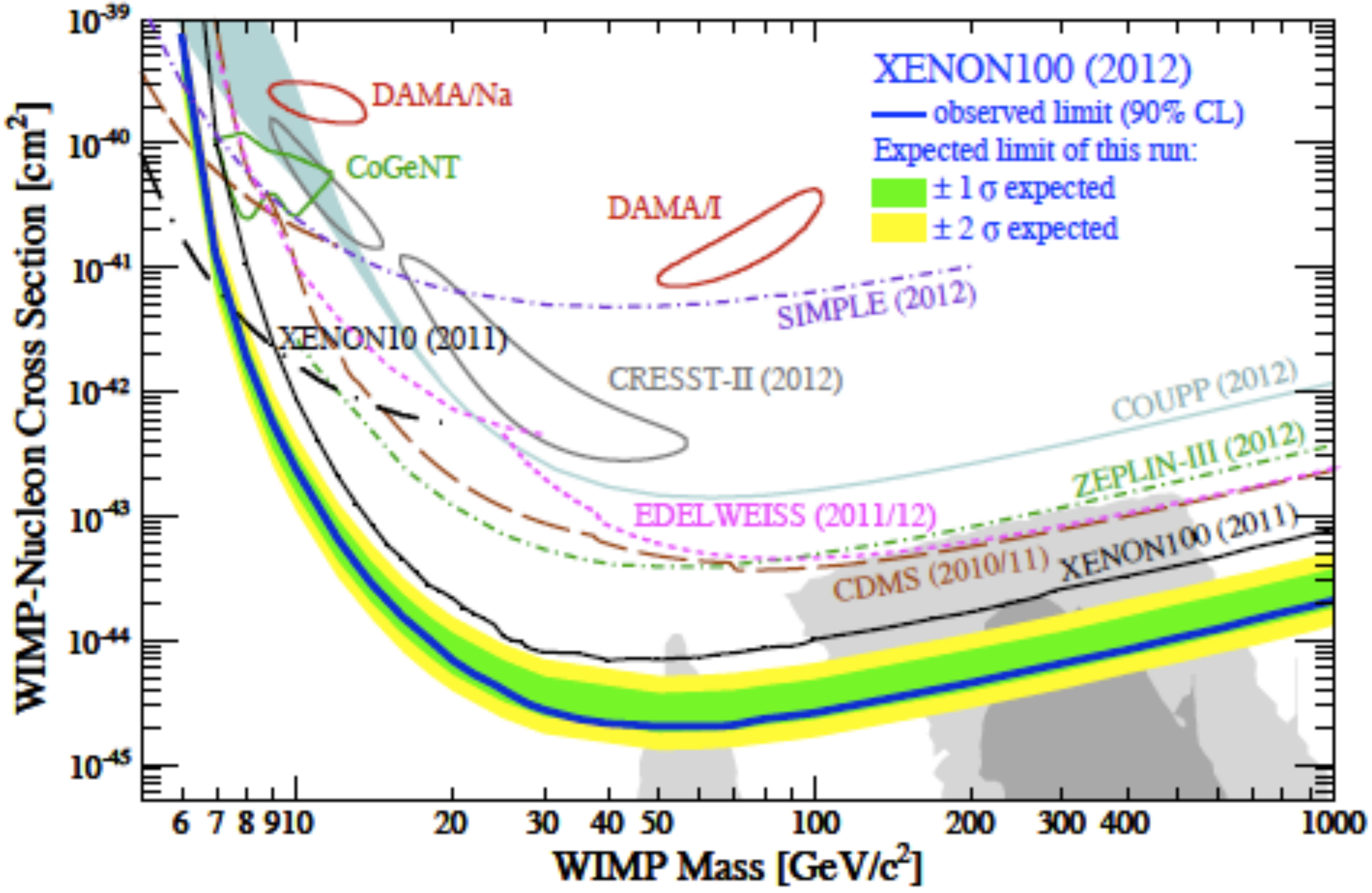
New Directions for Direct Detection of Dark Matter

Peter Graham
Stanford

Direct Detection Now

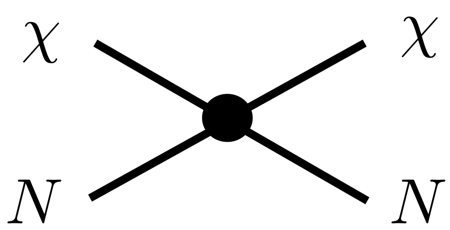


Many experiments will push down these limits for masses ≳ 10 GeV

Are there other directions to take?

- light WIMPs
- electron scattering
- new types of detectors

Light WIMP Scattering



for $m_\chi \ll m_N$

momentum transfer: $q \sim m_\chi v$

energy deposited: $E \sim \dfrac{m_\chi^2 v^2}{m_N}$

for very light WIMPs motivates searching for electron scattering

form factor in e$^-$ scattering makes heavy WIMPs difficult to detect

loop induced couplings to nucleons means electron scattering is already well covered at higher masses

Outline

1. Electron Scattering and Xenon10

   R. Essig, J. Mardon, T. Volansky

2. Electron Scattering with Semiconductors

   PWG, D.E. Kaplan, S. Rajendran, M. Walters

3. Polarized Detectors

   C. Chiang, M. Kamionkowski, G. Krnjaic

Light Dark Matter, Electron Scattering, and Xenon10

R. Essig, J. Mardon, T. Volansky

Proof of principle with XENON10

"Direct Detection of Sub-GeV Dark Matter" Essig, Mardon & Volansky arXiv:1108.5383

Calculated scattering rates of DM with bound electrons

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Dual-phase Noble Gas detectors have well established sensitivity to *individual electrons*

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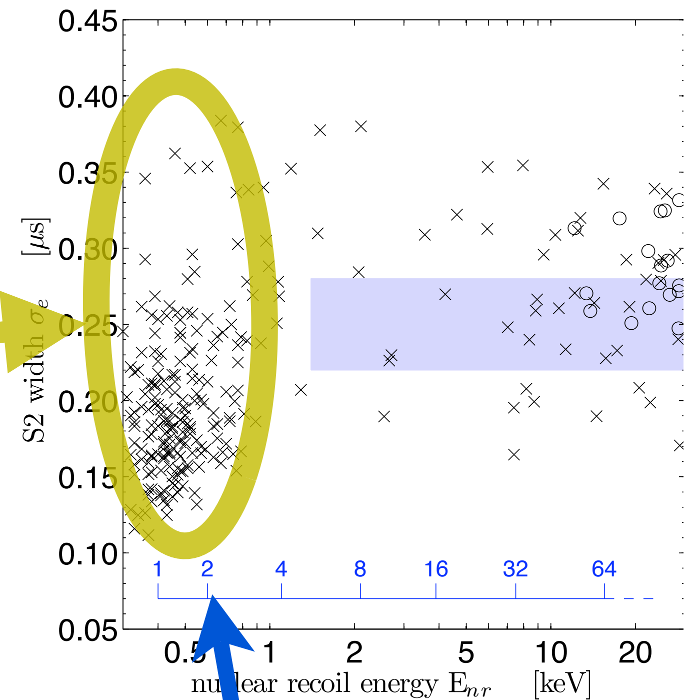
Calculated scattering rates of DM with bound electrons

Dual-phase Noble Gas detectors have well established sensitivity to *individual electrons*

XENON10 had the best sensitivity, but only recorded such small events during a short run in 2006:

"A search for light dark matter in XENON10 data"
XENON10 collaboration
1104.3088

single/few-electron events



number of electrons

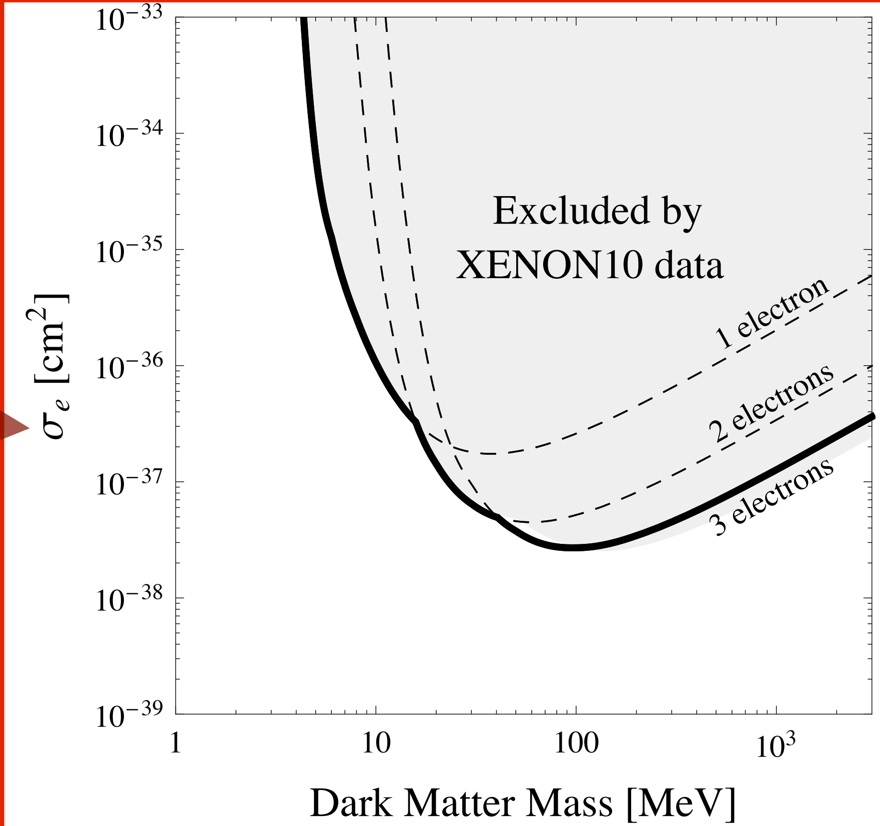
Proof of principle with XENON10

Essig et. al. used this data to constrain the rate of 1-, 2-, and 3-electron ionization events:

R(1-electron) < 39 [events per kg-day]
R(2-electron) < 4.7
R(3-electron) < 1.1

Comparing to theoretical prediction of expected event rate gave first direct detection bound on sub-GeV DM:

cross-section to scatter with free electron



"First Direct Detection Limits on sub-GeV Dark Matter from XENON10"

Essig, Manalaysay, Mardon, Sorensen & Volansky
arXiv:1206.2644

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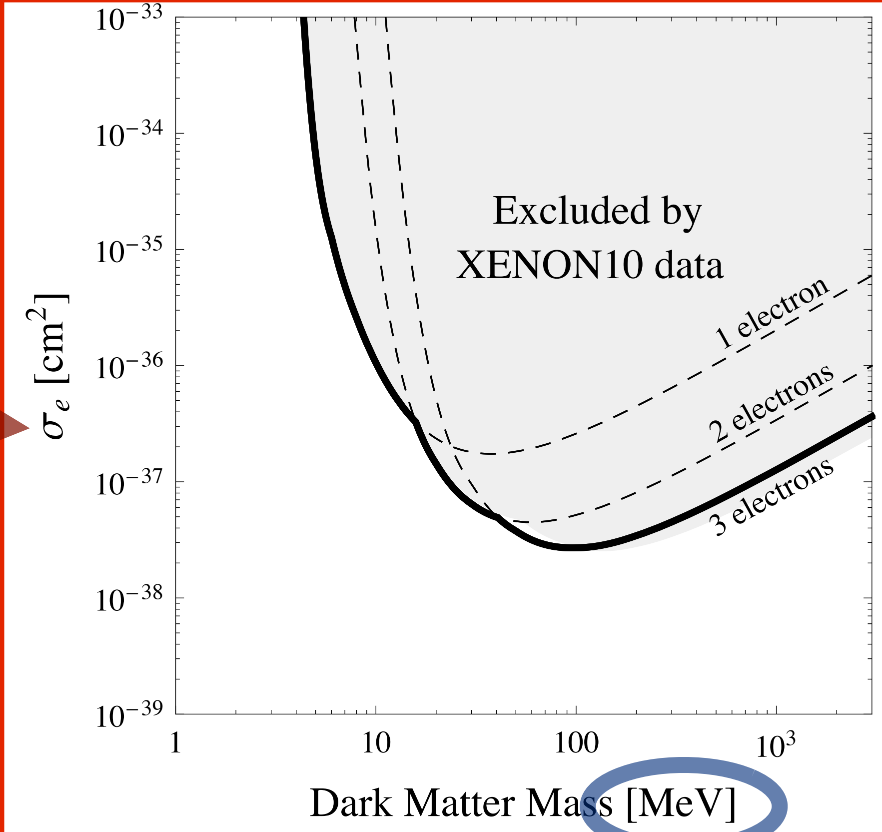

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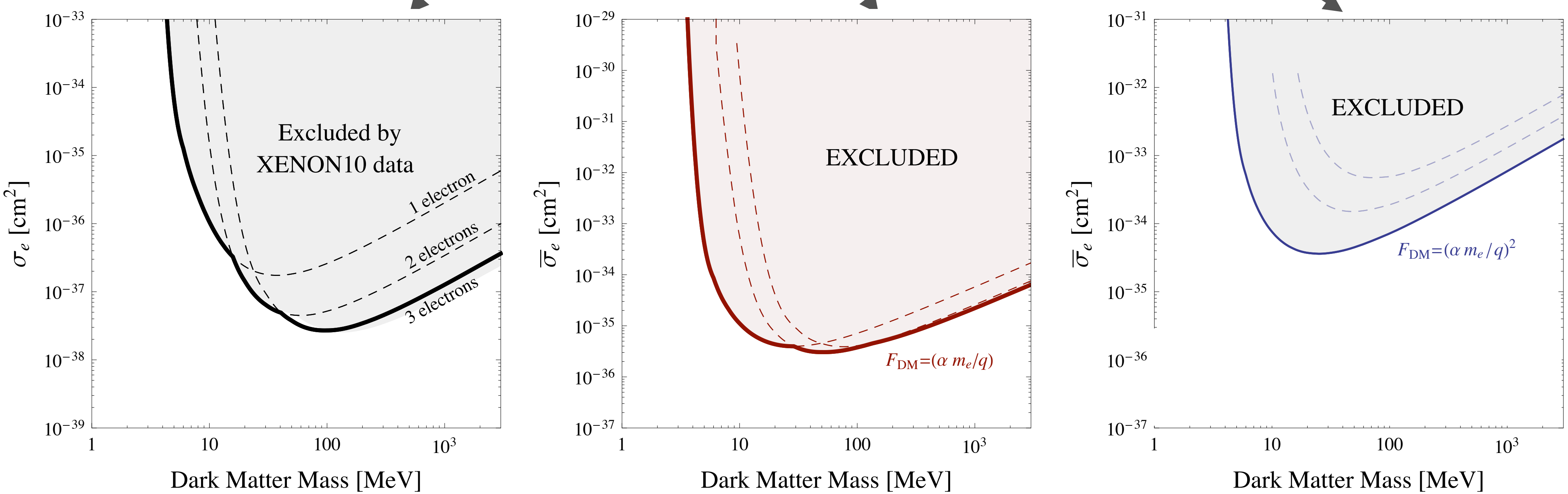
How does this compare to models?

different momentum-dependence of DM coupling



Essig et. al. 1206.2644

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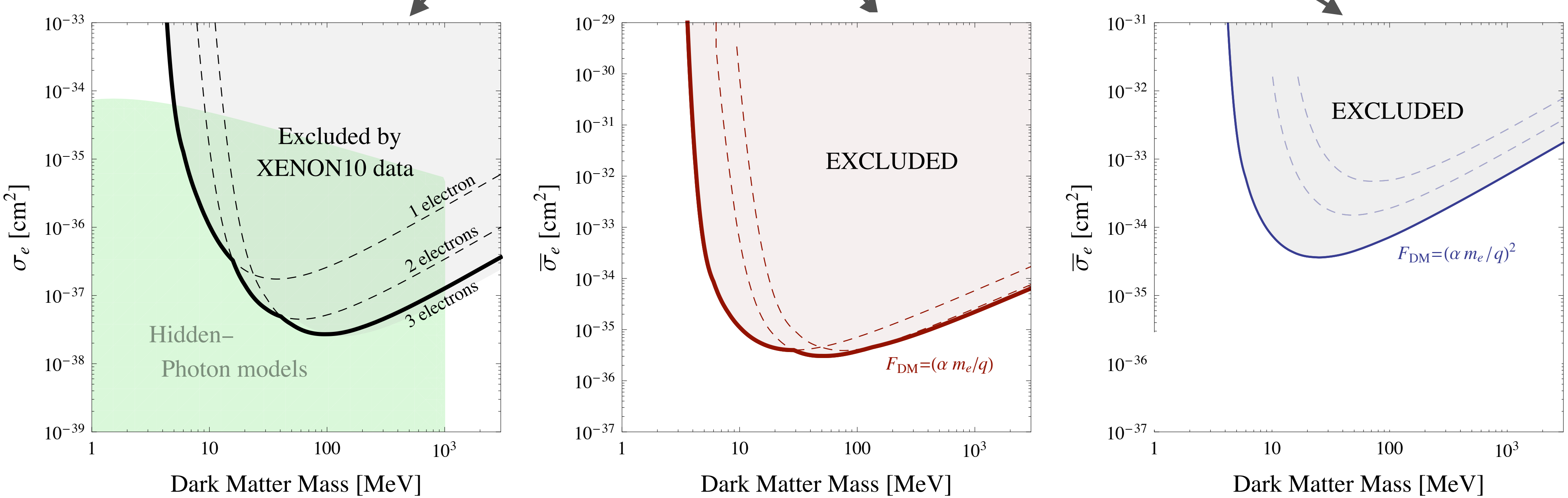
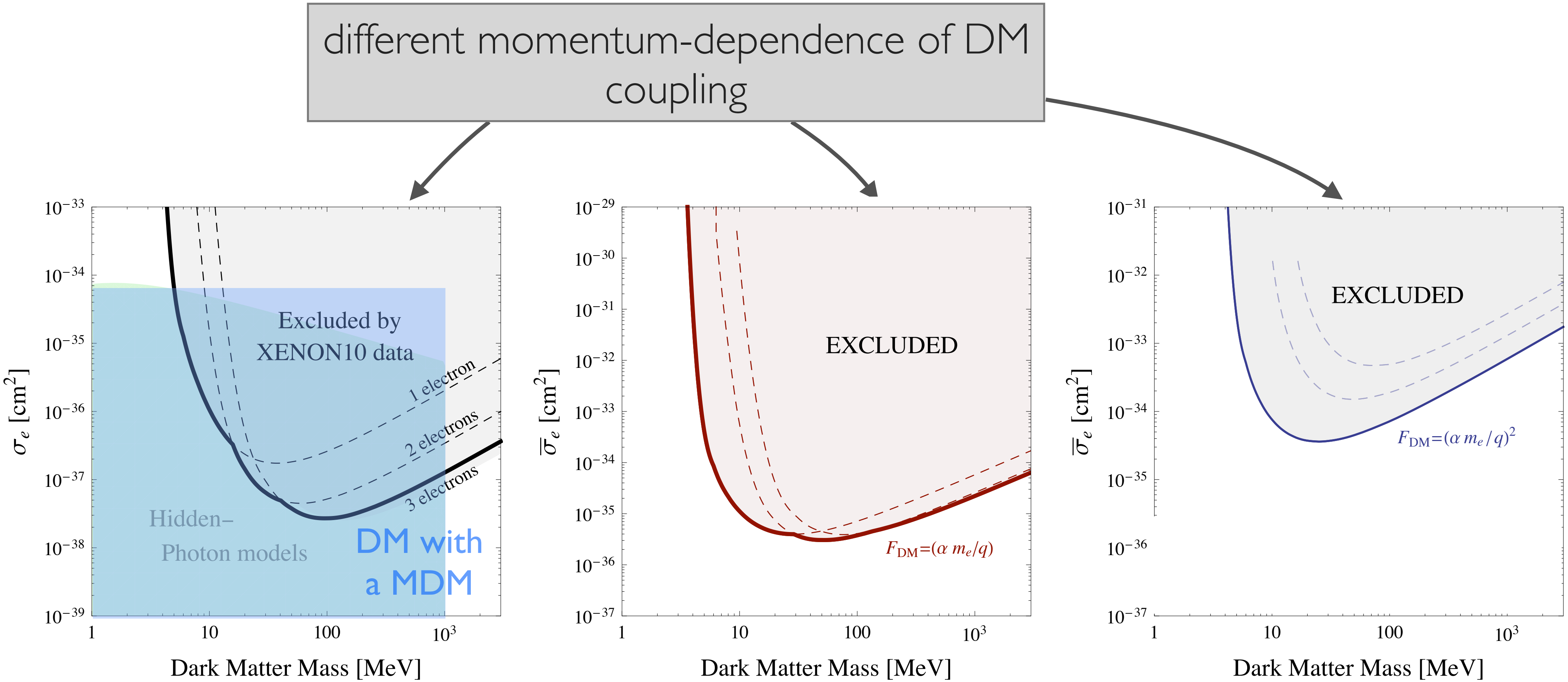


DM coupled via a light **A’ gauge boson** (A’ mass~10 MeV)

Essig et. al. 1206.2644

How does this compare to models?

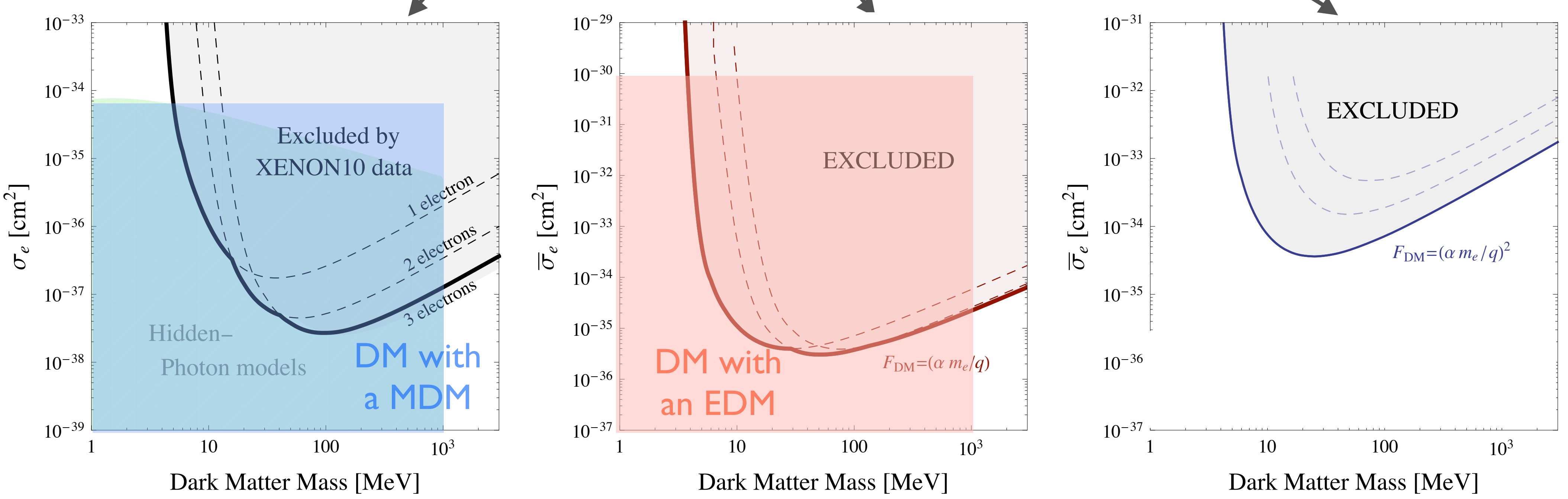


DM with a **magnetic dipole moment** (μ<TeV^{-1})

Essig et. al. 1206.2644

How does this compare to models?

different momentum-dependence of DM coupling

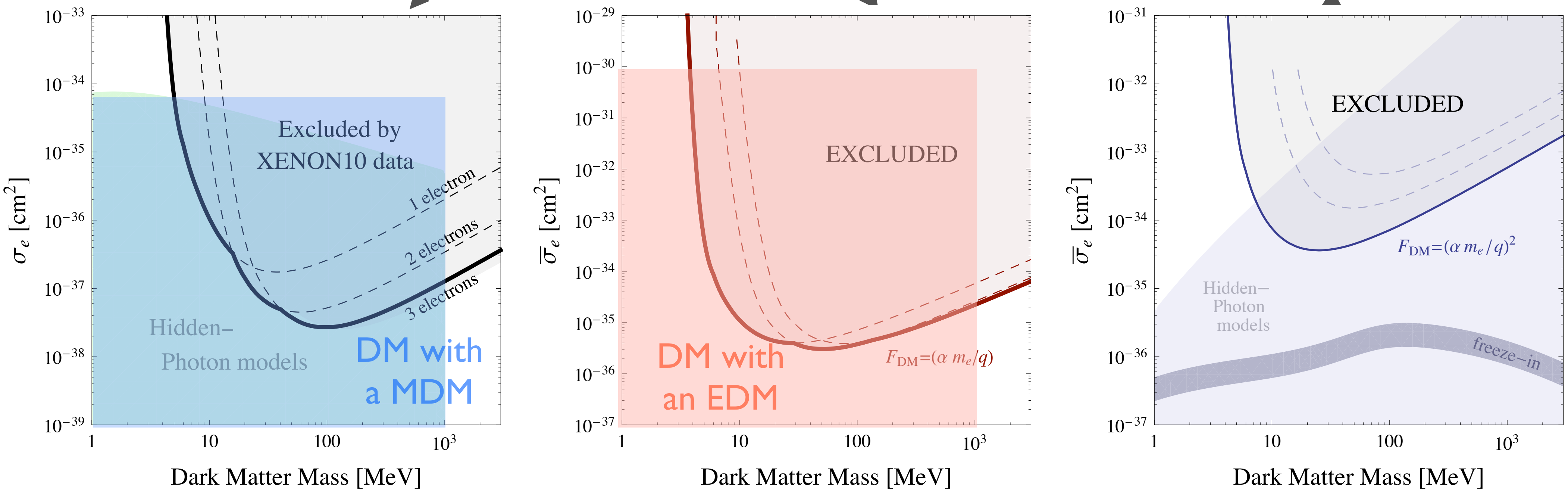


DM with an **electric dipole moment**
(d< TeV^{-1})

Essig et. al. 1206.2644

How does this compare to models?

different momentum-dependence of DM coupling



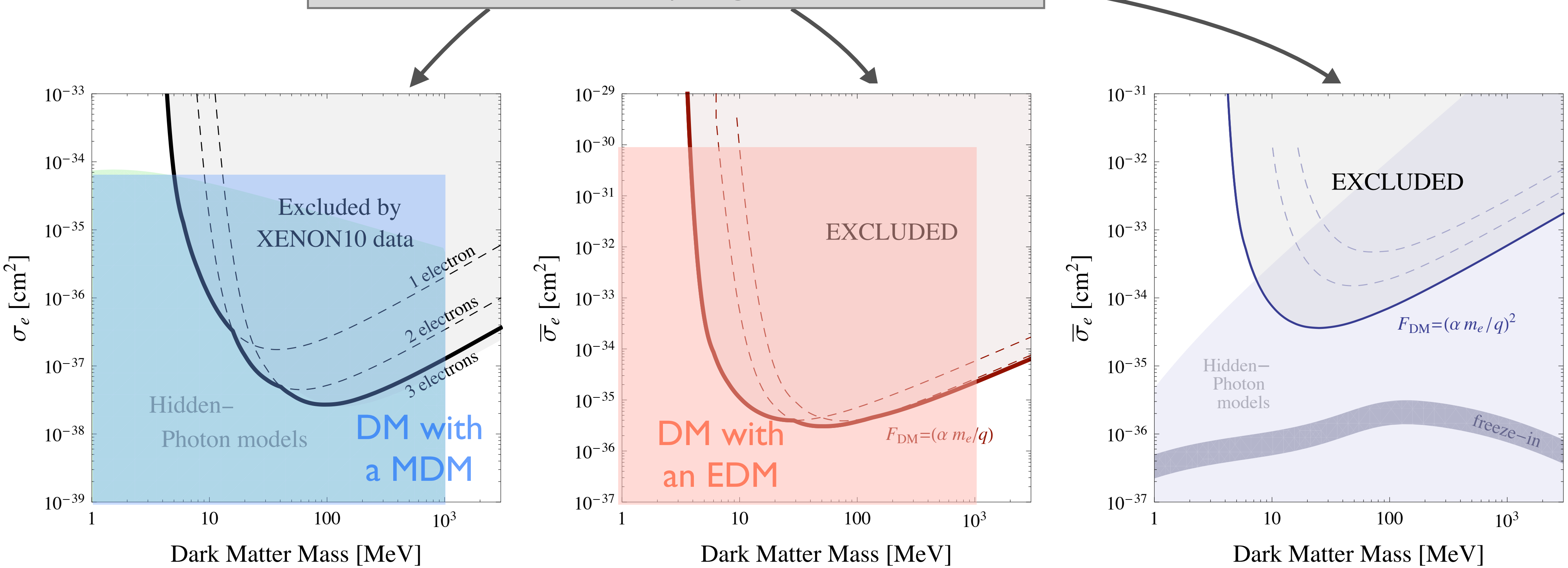
DM coupled via very light A' gauge boson

(mass<< keV)

Essig et. al. 1206.2644

How does this compare to models?

different momentum-dependence of DM coupling



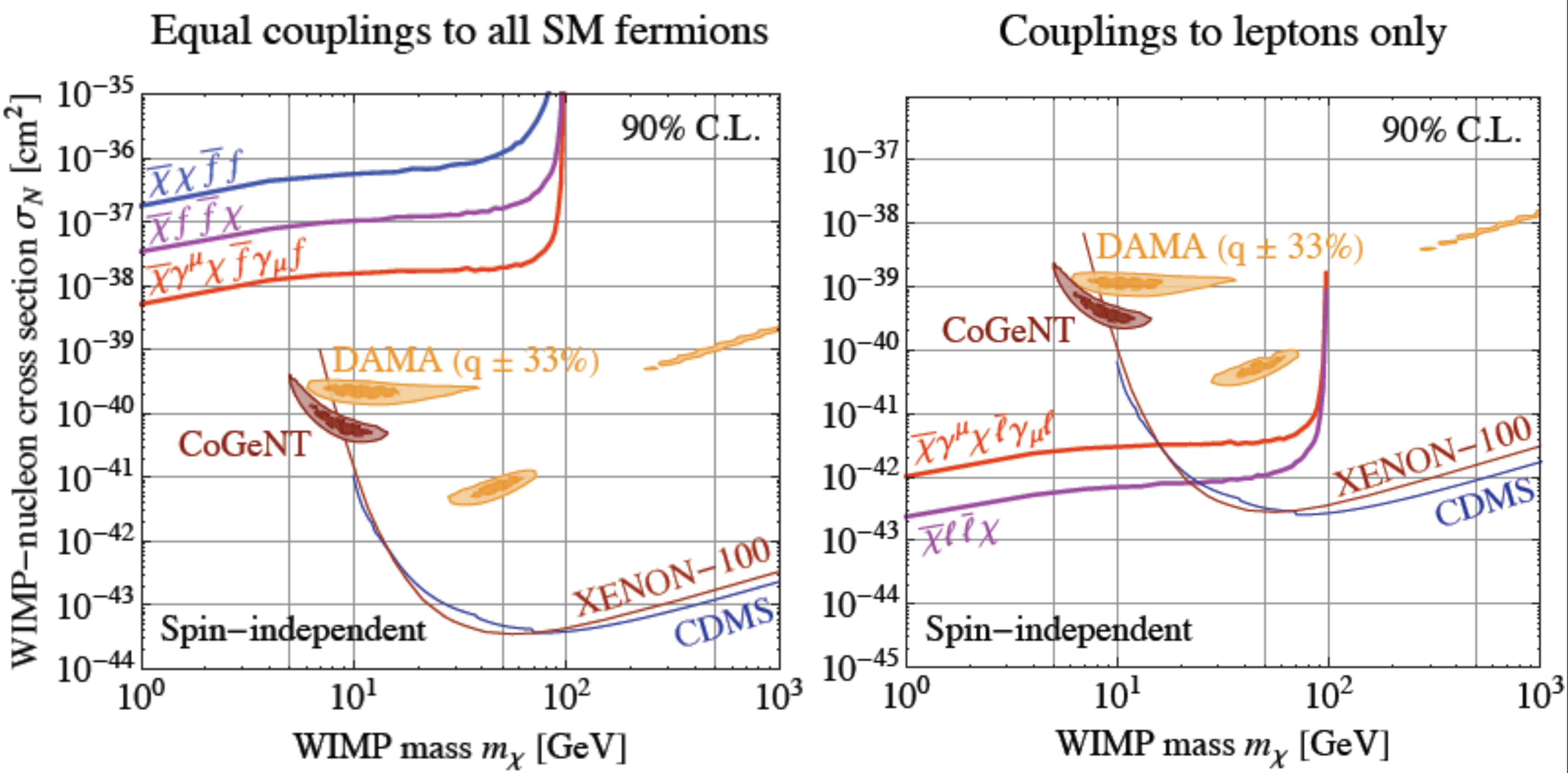
Interesting models already being probed

Essig et. al. 1206.2644

Semiconductor Probes of Light Dark Matter

PWG, D.E. Kaplan, S. Rajendran, M. Walters,
Phys. Dark Universe **1** (2012) 32, (arXiv:1203.2531)

Collider Limits



Fox, Harnik, Kopp, Tsai (1103.0240)

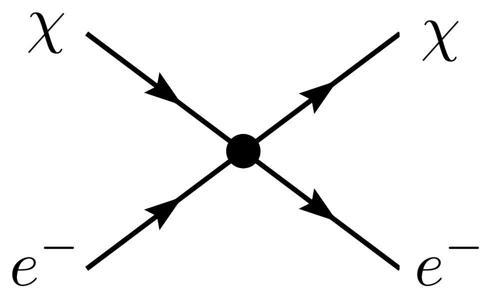
also see Goodman et. al. (2010)

Colliders already probe light WIMPs

Possible Interactions

- Dimension 6

$$\bar{\chi}\chi\bar{f}f$$



Already ruled out by colliders over the testable range

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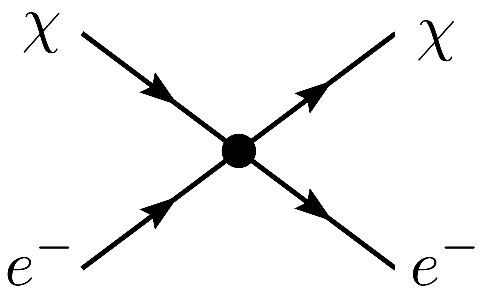
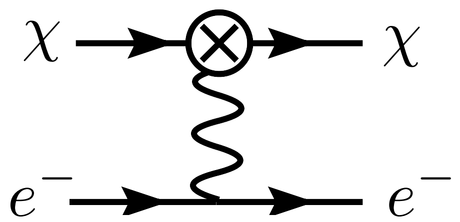


Already ruled out by colliders over the testable range

- Dimension 5

$$\bar{\chi}\sigma^{\mu\nu}(\mu + d\gamma^5)\chi F_{\mu\nu}$$



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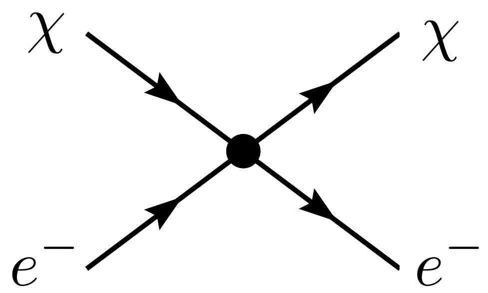

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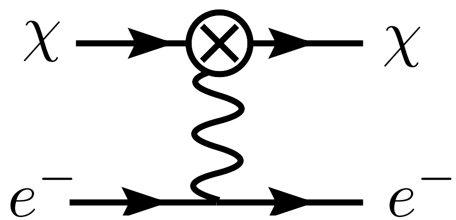
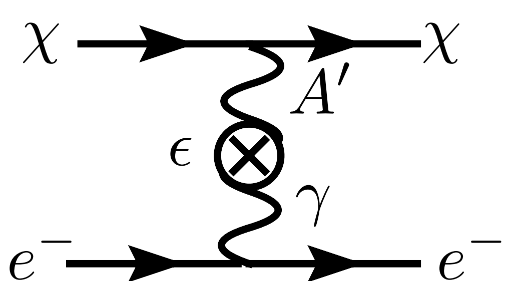


- Dimension 4

$$gA'_\mu\bar{\chi}\gamma^\mu\chi$$



Possible Interactions

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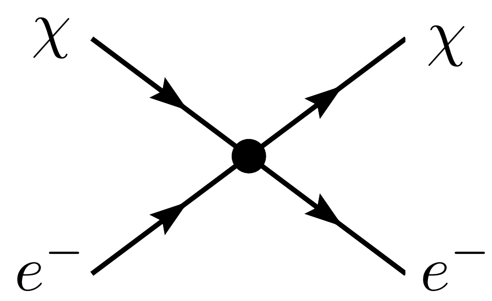

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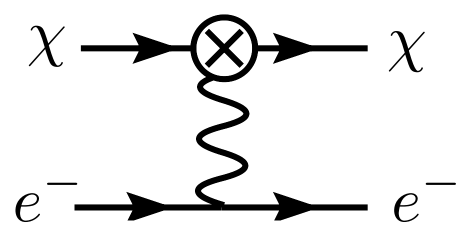
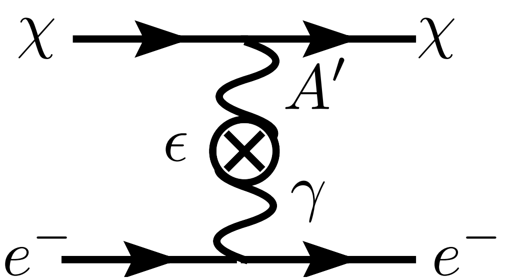


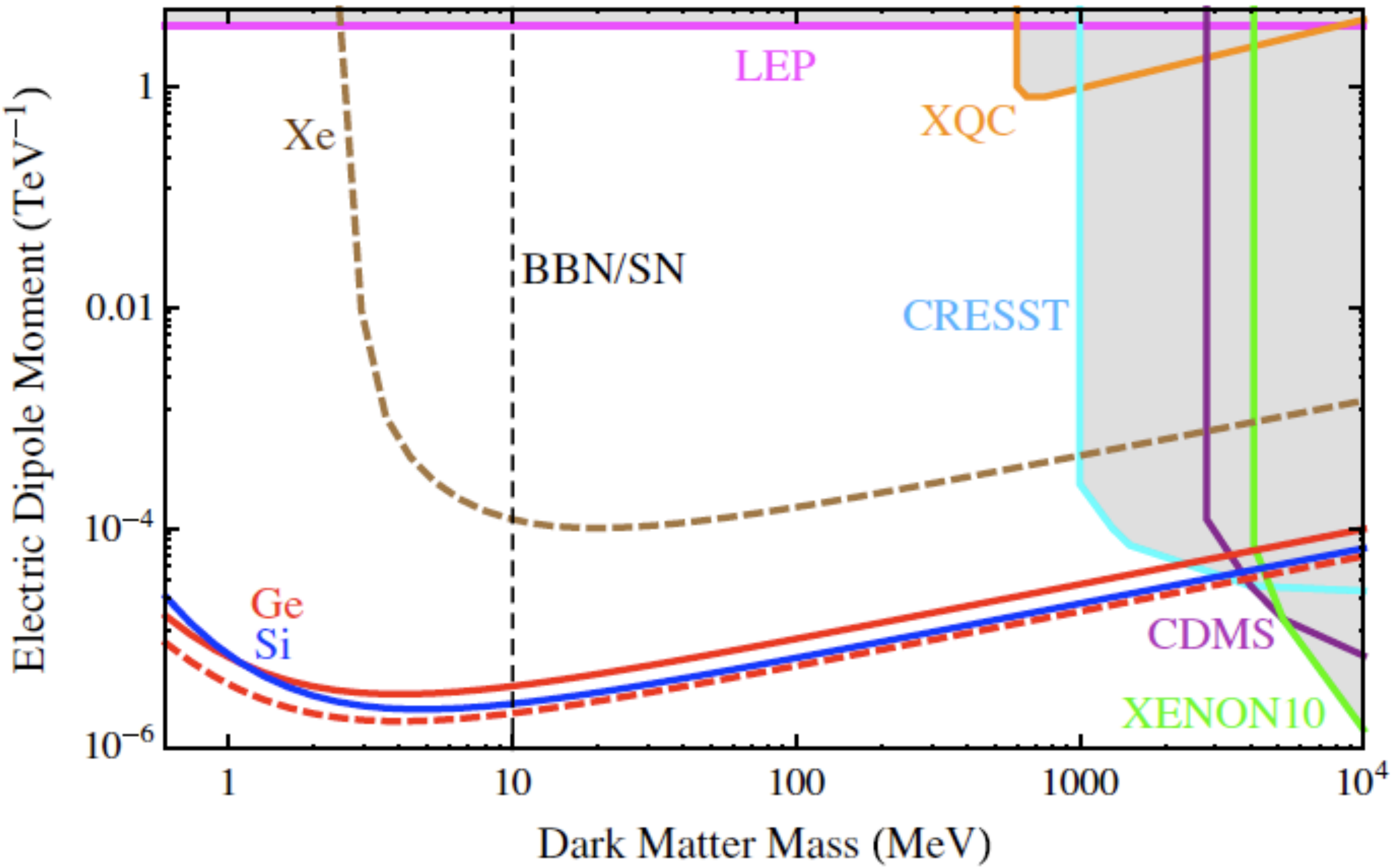
Light mediator increases σv at low WIMP velocity and avoids collider limits

- Dimension 4

$$gA'_\mu\bar{\chi}\gamma^\mu\chi$$



EDM Coupling Limits



CDMSLite

threshold ~ 1 eV

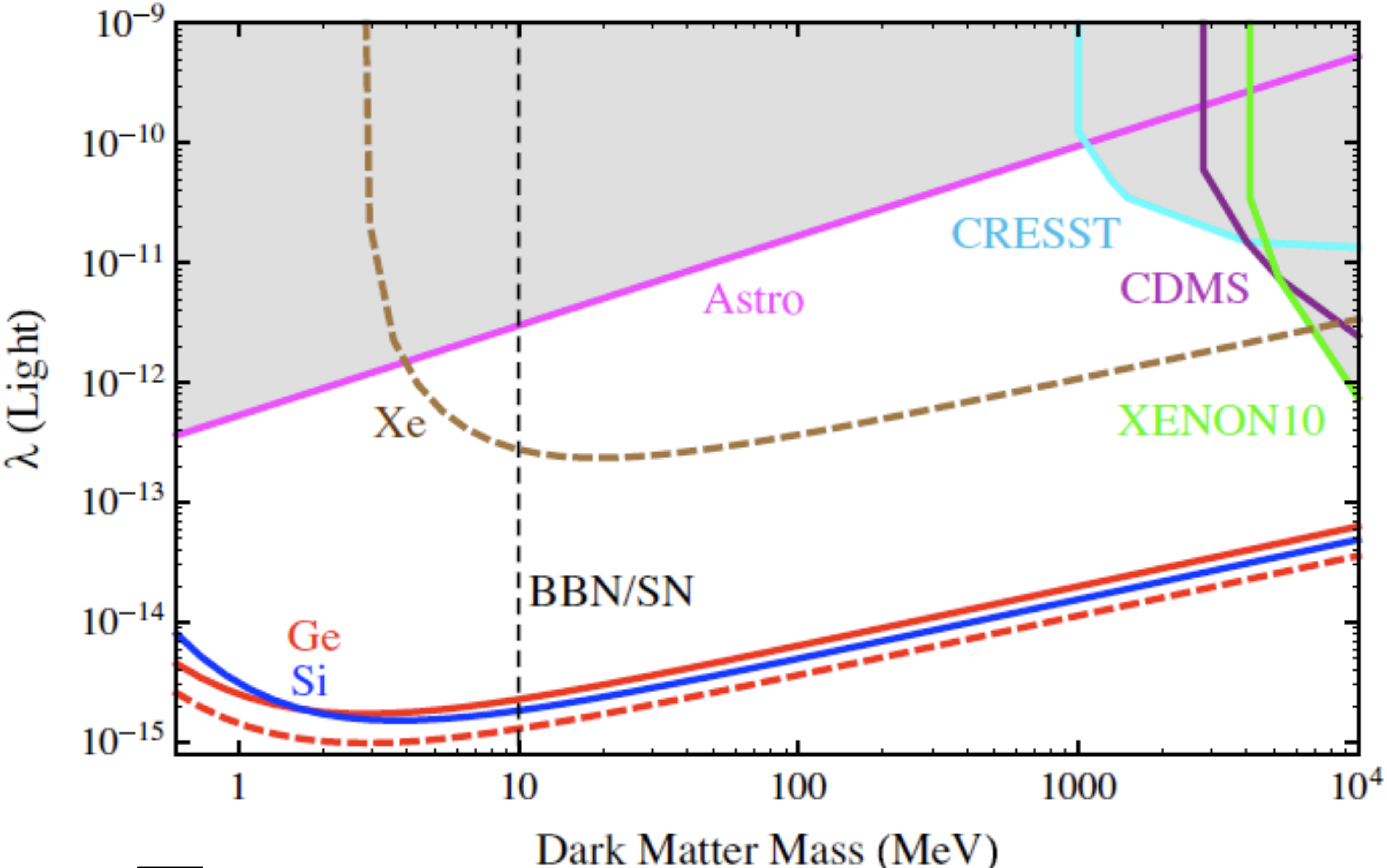
4.4 kg Ge

1.1 kg Si

1 event/kg/day/keV

Semiconductors could be good probes of light DM

A' Coupling Limits



$$\lambda = \epsilon\sqrt{\frac{g^2}{4\pi}}$$

Polarized Detectors

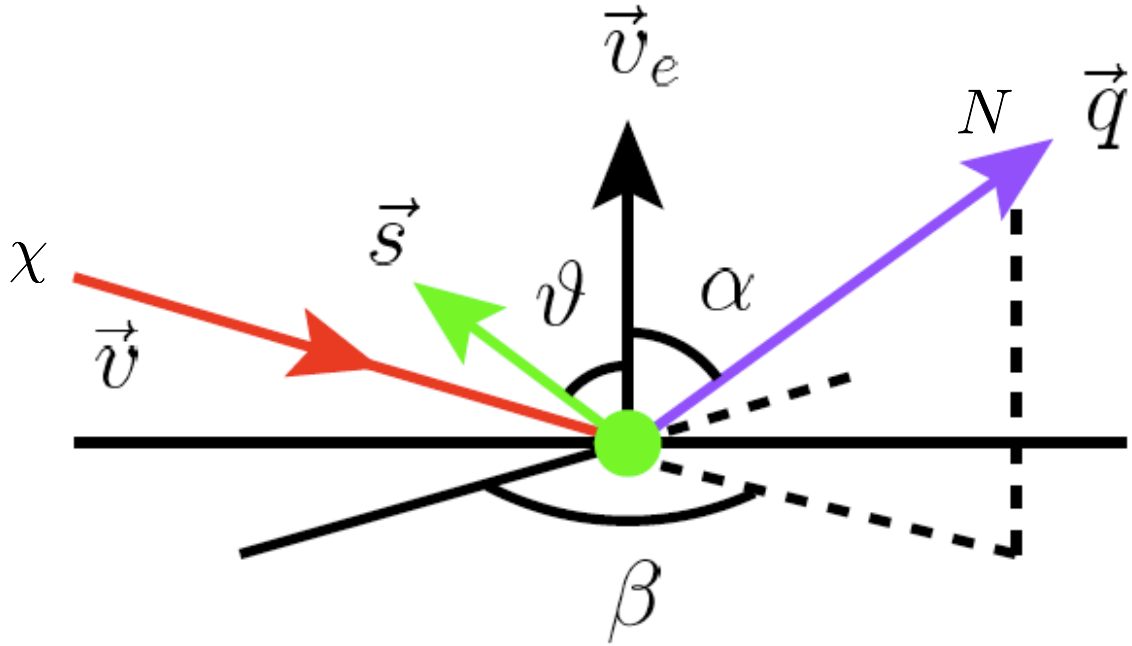
C. Chiang, M. Kamionkowski, G. Krnjaic
Phys. Dark Universe **1** (2012) 109 (1202.1807)

Polarized Scattering

If WIMP is a scalar, recoil is independent of nuclear spin direction

But if WIMP is a fermion with P-violating interactions: $\bar{\chi}\gamma^{\mu}\left(a+b\gamma_5\right)\chi\bar{N}\gamma_{\mu}\left(c+d\gamma_5\right)N$

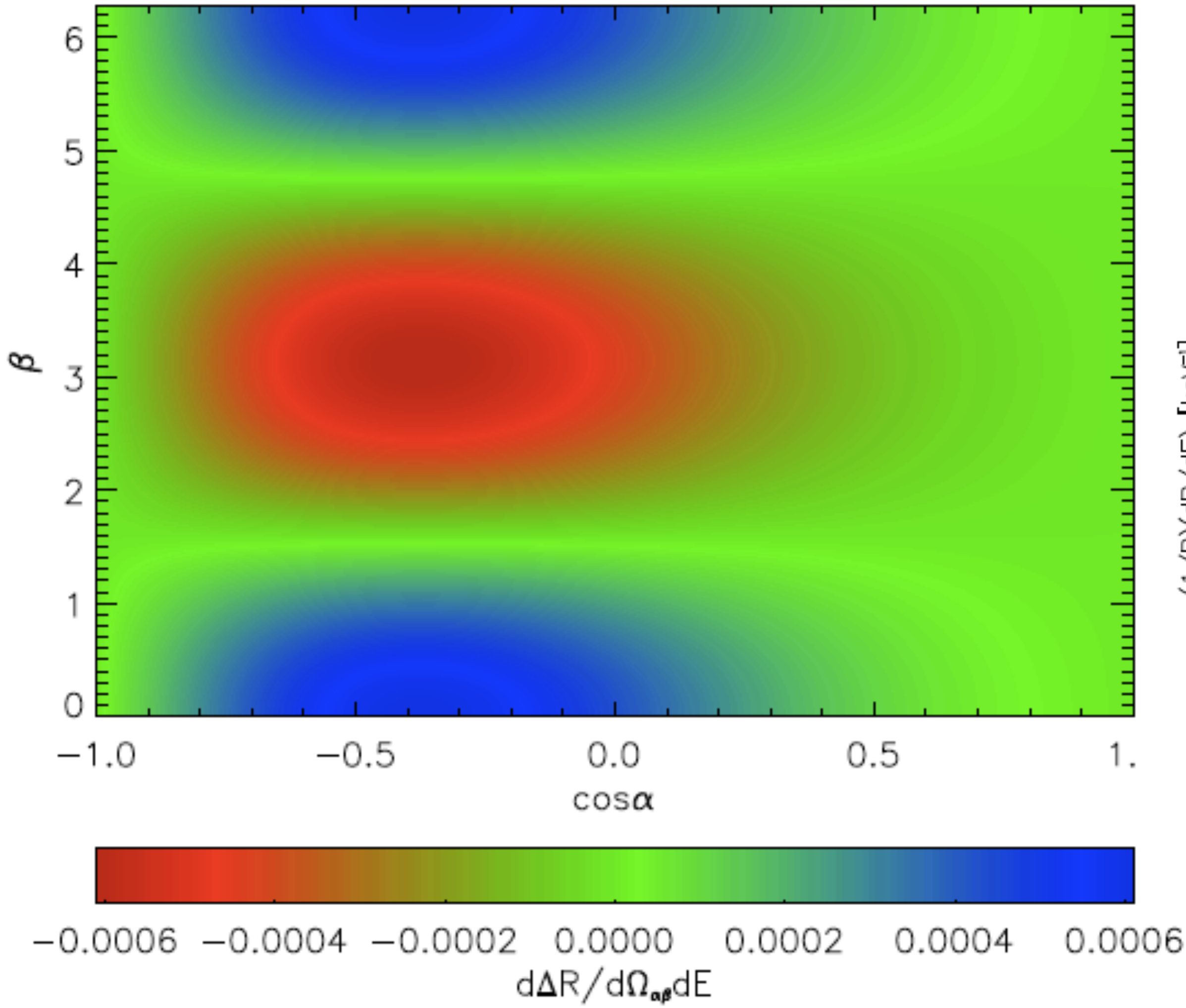
then total rate and energy/direction distributions can depend on nuclear polarization

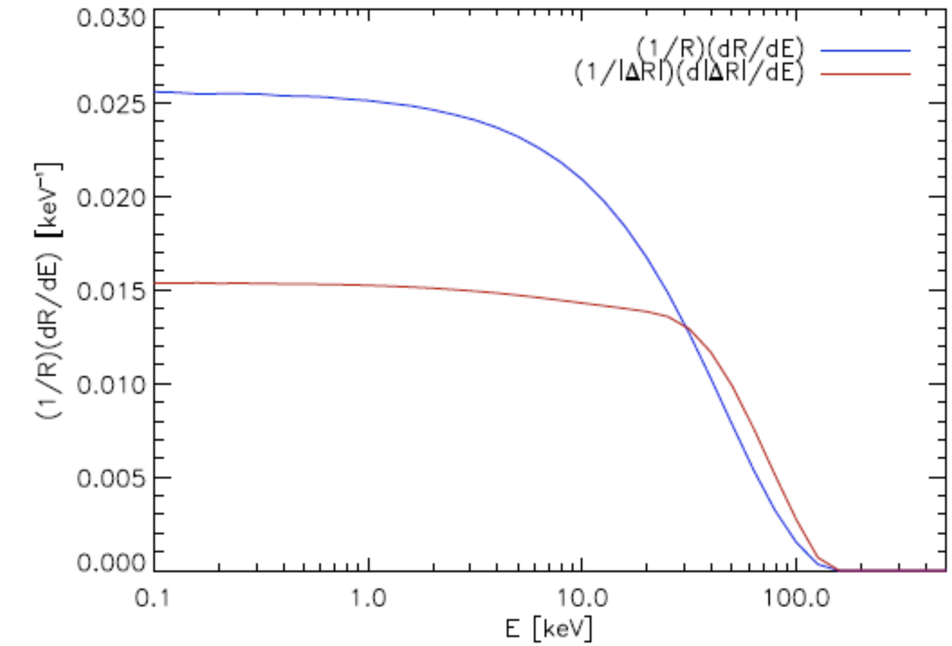


Need polarized nuclei and signal $\propto v_e \sim 10^{-3}$

Differential Event Rate

ΔR = difference in rate between opposite polarizations





Polarization angle gives information on dark matter model, may help reject backgrounds

some information without directional detection, but more with it